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ABSTRACT

The achievement of bilingualism appears to have positive consequences for the bilingual child, enhancing universal aspects of cognitive functioning available to all normal children. However, little is yet known about the interaction between educational treatment and the input factors the bilingual child brings to the situation. Focusing on the interaction of a science inquiry program with aspects of cognitive functioning and bilingualism, this paper presents empirical evidence that bilingualism has a positive effect on the ability of students to formulate scientific hypotheses or solutions to science problems. It compares the effects of teaching hypothesis formation to bilingual children proficient in both Spanish and English with results from monolingual English-speaking children. The children were 11-year-old sixth graders in 6 intact classrooms in the Philadelphia area and in San Antonio, Texas. Three groups were monolingual and three were bilingual; they were matched for other variables. Previous studies had indicated that cognitive ability to formulate scientific hypotheses functions independently of socio-economic level. Results show that children in the bilingual experimental groups performed significantly better than the monolinguals. The hypothesizing process is discussed in terms of Piaget's theory, and implications are drawn for both language and science education. (AMH)

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CONSEQUENCES OF BILINGUALISM IN A SCIENCE INQUIRY PROGRAM

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CONSEQUENCES OF BILINGUALISM IN A SCIENCE INQUIRY PROGRAM

Carolyn Kessler and Mary Ellen Quinn

Unlike the acquisition of a first language, a universal developmental phenomenon achieved by all normal children in all cultures, bilingualism or the acquisition of a second language is a nonuniversal achievement. Bilingualism, as other nonuniversal developmental advances, may be presumed to draw on the same conditions that describe processes for general cognitive development in children which set the stage for first language acquisition. Like universal achievements, nonuniversals also require cognitive conflicts as a precondition for cognitive development. A feature which distinguishes nonuniversal from universal achievement, as Feldman (1980) explains, is that the former tend to require some form of instruction or facilitating conditions for their acquisition. The nonuniversal achievement of bilingualism appears, through mounting empirical evidence, to have positive consequences for the bilingual child, enhancing universal aspects of cognitive functioning available to all normal children. Little is yet known, however, about the interaction between educational treatment and the input factors the bilingual child brings to the situation.

Focusing on the interaction of a science inquiry program with aspects of cognitive functioning and bilingualism, this paper presents empirical evidence that bilingualism has a positive effect on the ability of students to formulate scientific hypotheses or solutions to science problems. It then offers a possible explanation for that positive effect together with implications for educational programs.

From the standpoint of psycholinguistics, cognitive and language development are intimately related, as indicated in the vast body of research that has emerged in the past decade. During this period, research in science education has consistently indicated that children's active engagement in science inquiry activities, which tap cognitive processes, has positive consequences for language development in both the spoken and written modes.

Among researchers investigating effects of science education on language development, Rowe (1970) found that inner city first graders produced 200 percent more spontaneous language during science activities than during so-called language arts instruction. In separate studies, Newman (1970) and Kellogg (1971) observed that primary grade children when given science instruction scored significantly higher on reading readiness tests than comparable control groups. Huff and Languis (1973) report an increase in oral communication abilities for kindergarten children given science instruction. Bethel (1974) found a positive effect of science experiences were based on an inquiry-approach focusing on cognitive processes such as observation, classification, measurement, inference, and prediction.

Contemporary models of science education with their focus on inquiry give a critical role to divergent thinking and the ability to formulate hypotheses in problem-solving situations. The acquisition and development of good hypothesizing abilities are, therefore, essential aspects of an effective science curriculum, along with the abilities to make accurate, detailed observations, enlightened inferences, and an adequate selection of variables.

In solving problems, students must select and order varied types of information or data, presumably by using concepts that they know. Inquiry addresses itself primarily to using concepts, only secondarily to learning concepts; clearly, however, an end product of any inquiry process may be the development of a new idea or concept. Science education, then, is concerned with making students more effective inquirers who efficiently make use of the abilities which serve as precursors to problem-solving.

Studies of the relationships between science education programs and language development have focused on monolingual English-speaking children. They leave open the unique issue of the bilingual child, who from language onset is either simultaneously developing in two languages or is undergoing the encoding of a second language in the childhood years. Much more extensive empirical research is needed

on cognitive and linguistic interdependence in the context of education programs and in the light of theoretical perspectives on cognitive development.

Emphasis in this paper is on the older child, specifically 11-year-old sixth graders who, according to Piaget's schema, may be candidates for a transitional stage between operational and formal thought. Rather than examining the range of processes involved in science inquiry programs, focus here is on the role of hypothesis formation as a central process in the solution of science problems and in the development of language. Results of the same treatment motivating hypothesis formation given by the same teacher in intact classrooms of sixth-graders ranging from monolingual English-speakers to proficient bilingual Spanish-English speakers are presented. Results from these experimental groups are compared with control groups. Bilingual children are here defined as those children who can produce complete and meaningful utterances in two languages (McLaughlin, 1978). Possible explanations for the observed positive effect of bilingualism together with implications for educational programs are considered.

Since the early 1960s an increasing number of studies have shown the positive consequences of bilingualism on intellectual functioning. In a benchmark study, Peal and Lambert (1962) obtained results with French-English bilingual children in Montreal and a control monolingual English group that suggested bilinguals may have a more diversified and flexible thought-structure. Replications of this study have consistently confirmed these results. Controlling for relative linguistic proficiency as well as socioeconomic level, De Avila and Duncan (1979) studied nearly 300 children in grades one and three in the United States and Mexico on measures of cognitive functioning. Comparing bilingual children fully proficient in two languages with children fully competent in only one language, they found a cognitive advantage for bilingual children on both Piagetian-type conservation tests and Witkin-type cognitive style measure of field independence/dependence. In a related cross-sectional study,

Duncan and De Avila (1979) subdivided four groups of Spanish-English bilingual children according to relative language proficiency ranging from proficient bilinguals to late language learners with low proficiency in both languages. Their findings indicate that increasing proficiency in two languages predicts higher scores on measure of perceptual disembedding or field independence/ dependence.

Lambert (1977) has suggested that the consequences of bilingualism may be dependent on the dominance relationship of the bilingual's two languages. He distinguishes between additive bilingualism, characterized by the acquisition of a second language without loss to the first, and subtractive bilingualism, the replacement of the first language by a second language. Relatively few research studies have examined the effects of these types of bilingualism on cognitive functioning, yet these are varieties of bilingualism commonly occurring in school settings.

In pointing out that some of the positive effects of bilingualism appear to depend on the degree of bilingualism attained, Cummins (1979-1980) has argued that there may be threshold levels of linguistic competence that bilingual children must reach before the potentially positive effects of bilingualism on cognitive functioning can be observed. This threshold hypothesis holds that those aspects of bilingualism which exert positive influences on cognitive functioning are unlikely to come into effect until the bilingual child has reached a certain threshold level of competence in both languages. For Cummins (1978) linguistic competence refers to the ability to make effective use of the cognitive functions of language. More specifically, it is to use language effectively as an instrument of thought and to represent the thinking processes by means of language.

One explanation of the hypothesis that bilingualism can influence the development of cognition can be found in the theory of cognitive development presented by

Piaget (1970). Although Piaget does not specifically address the issue of bilingualism, his position on cognitive development and its relationship to language development has implications for an understanding of the consequences of bilingualism.

Following the theory current in developmental psycholinguistics that language acquisition results from processes utilizing hypothesis formation and testing to construct an internalized set of rules or grammar of the language, we hypothesize that children specifically taught to improve the quality of their hypotheses formulated in a science class will give evidence of progressing to more complex levels of language development. Chomsky (1969) in a study of monolingual English-speaking children found that children at age 10 have not developed some of the more complex structures of English. Kessler (1971) in studying Italian-English bilingual children found that the upper limits of acquisition of certain syntactic structures had not been reached in the 9-year-olds in her sample. One may assume, then, that sixth graders are still in the process of developing various linguistic structures.

Quinn (1971) and Quinn and George (1975) demonstrated that monolingual English-speaking children can be taught to form scientific hypotheses of increasingly high quality. In evaluating a method for teaching hypothesis formation to monolingual sixth-grade children in two different socio-economic settings, Quinn concluded that, under the conditions described in the study, the quality of the hypotheses elicited in a science inquiry program can be measured. She found a significant difference ($p < .001$) between the quality of hypotheses generated by students receiving instruction in formulating scientific hypotheses and those who did not. Table 1 outlines the experimental design.

TABLE 1

EXPERIMENTAL DESIGN

	Sequence of Procedures		
	1	2	3
Control Group	Covariable Test	Criterion Variable Test	Treatment
Experimental or Treatment Group	Covariable Test	Treatment	Criterion Variable Test

Table 2 gives the design for comparing socio-economic levels of treatment groups for monolingual English-speaking children.

TABLE 2

TWO BY TWO FACTORIAL DESIGN TO COMPARE TREATMENTS AND SOCIO-ECONOMIC LEVELS

	Socio-Economic I	Socio-Economic II
Treatment	(1 1)[a]	(1 2)
No Treatment	(2 1)	(2 2)

[a]Cell code

Quinn concluded that the formulation of scientific hypotheses can be taught, that the quality of the hypotheses elicited can be measured, and that a significant difference (p .001) exists between the quality of hypotheses generated by students who received instruction in hypothesis formation and those who did not. Table 3 displays the analysis of covariance for experimental monolingual English-speaking groups and socio-economic level.

TABLE 3

ANALYSIS OF COVARIANCE FOR TREATMENT
AND SOCIO-ECONOMIC LEVEL

Source of Variation	Adjusted SS	DF	MS	F	P Less Than
Treatment	34453.320	1	34453.320	113.698	0.001
Socio-economic Level	0.084	1	0.094	0.000	0.986
Treatment X S-E Level	172.648	1	172.648	0.570	0.451
Within Cells	51817.242	171	303.025		

Results from four groups of sixth-grade children in Philadelphia, Pennsylvania, a control and an experimental group from an upper middle class suburban socio-economic level and a control and an experimental group from a lower working class urban socio-economic level, indicated that the cognitive ability to formulate scientific hypotheses functions independently of socio-economic level.

With socio-economic level identified as a non-significant variable in the ability to generate increasingly complex scientific hypotheses, Kessler and Quinn (1979) conducted a pilot study comparing the effects of non-balanced bilingualism with monolingualism in English on the ability to formulate scientific hypotheses. Using an experimental group for which all procedures as well as the teacher were held constant, results obtained from 28 sixth-graders in an intact classroom in a low socio-economic area of Philadelphia indicated that the ability to generate hypotheses favors bilinguals, even when bilingualism is subtractive. The sample used in this exploratory study of the effects of bilingualism on formulating scientific hypotheses included a group of 14 English-speaking monolingual children and 14 Italian-English bilinguals in the process of replacing their first language, Italian, with English. Both groups

were matched on I.Q. scores as measured by the Otis Quick-Scoring Mental Ability Test, Beta, Form FM. All of the children came from a low socio-economic neighborhood in which the school was situated.

The observed positive effects of non-balanced or subtractive bilingualism leads to questions regarding the effects of additive, proficient bilingualism on children's ability to formulate scientific hypotheses. This report, part of an extended study (Kessler and Quinn, 1980, in press), compares the effects of teaching hypothesis formation to bilingual children proficient in both Spanish and English with results from monolingual English-speaking children.

Subjects

The subjects of this investigation were sixth grade students in six intact classrooms. One experimental and one control group were monolingual English-speaking children from an upper socio-economic area in suburban Philadelphia, Pennsylvania (SES-1). Another experimental and control group of monolingual English speakers came from a low urban socio-economic area in South Philadelphia (SES-2). Also related to this group were the subtractive Italian-English bilingual children who participated in the pilot study on the effects of subtractive bilingualism on hypothesis formation in the context of a science inquiry program. The third set of children consisted of Spanish-English additive bilingual children in a very low socio-economic area of San Antonio, Texas (SES-3). These Mexican-American students had participated in bilingual education programs during the primary grades, K-3. They were first language speakers of Spanish who had acquired English as a second language in school. By grade 6 all instruction was in English, but Spanish continued to function in peer interactions, in the home and community. According to demographic information from census-data, the additive bilinguals represented the lowest socio-economic level investigated.

The monolingual experimental and control groups were matched for grade level as well as the following variables: 1) I.Q. as measured by the Otis Quick-Scoring Mental Ability Test, Beta, Form FM; 2) reading scores as measured by Part III of

the Pupil Progress Series, Diagnostic Reading Test; 3) overall grade-point average. The experimental and control bilingual groups were matched on mathematics scores, science scores, and reading scores, all as measured by the Comprehensive Test of Basic Skills, Level 2, Form S.

Methodology

Subjects in the three experimental groups participated in a series of 12 science inquiry film sessions and 6 discussion sessions, each 40 minutes in length. The problem-presentation sessions were based on film loops of the Inquiry Development Program in Physical Science developed by Suchman (1962). Each 3-minute film loop depicts a single physical science problem. At the end of each film session students wrote as many hypotheses as they could in a rigorously controlled 12-minute period. The individual papers were then scored on two criteria: The Hypothesis Quality Scale developed by Quinn (1971) and the Syntactic Complexity Formula developed by Botel, Dawkins and Granowsky (1973). The Hypothesis Quality Scale is given in Table 4.

TABLE 4

HYPOTHESIS QUALITY SCALE

Points Given	Criterion
0	No explanation, such as a nonsense statement, a question, an observation, a single inference about a single concrete object.
1	Non-scientific explanation, such as "...because it's magic" or "...because the man pushed a button"
2	Partial scientific explanation, such as incomplete reference to variables, a negative explanation, an analogy.
3	Scientific explanation relating at least two variables in general or non-specific terms.
4	Precise scientific explanation, a qualification and/or quantification of the variables.
5	Explicit statement of a test of an hypothesis. (An inference is made here that the child who states a test is also able to adequately and precisely hypothesize.)

Quinn validated the definition of an hypothesis as a testable explanation of an empirical relationship between at least two variables in a given problem situation through analyzing the philosophy of science literature, using in particular the works of Poincaré (1952), Popper (1959), Hanson (1968), Caws (1969), and Black (1946). From these works she synthesized the following criteria for judging the quality of a hypothesis: 1) it makes sense, 2) it is empirically based, 3) it is adequate, 4) it is precise, and 5) it states a test of its validity. Based upon the criteria for evaluating hypotheses, the scale reflects a continuous variable with a zero to five range for scoring each hypothesis. A zero score is given for no explanation (i.e., a nonsense statement, a question, an observation, a single inference about a single concrete object); one for a non-scientific explanation (i.e., 'because it's magic'), two for a partial scientific explanation (i.e., incomplete reference to variables, a negative explanation, an analogy); three for a scientific explanation relating at least two variables in general or nonspecific terms; four for a precise scientific explanation, a qualification and/or quantification of the variables; five for an explicit statement of a test for a precise scientific explanation. Quinn found an interrater realiability of .94 using the Nash-Beyers computer program based on Winer (1962) as shown in Table 5.

TABLE 5

INTERJUDGE RELIABILITY OF THE HYPOTHESIS QUALITY SCALE

Source of Variation	Sum of Squares	DF	Mean Square	F
Among Subjects	367.840	49	7.507	
Within Subjects	43.333	100	0.433	
Among cols. 0.653		2	0.327	0.750
Residual 42.680		98	0.436	
TOTAL	411.173	149		

Column Number	Mean	Standard Deviation
1	2.460	1.775
2	2.560	1.527
3	2.620	1.701

Unadjusted reliability = 0.942

Results

Mean scores for hypothesis quality and syntactic complexity of the language used to express the hypotheses are given for monolingual and bilingual experimental and control groups in Table 6.

TABLE 6

HYPOTHESIS QUALITY AND SYNTACTIC COMPLEXITY MEAN SCORES
MONOLINGUALS AND BILINGUALS

Group \ Variable		N	Hypothesis Quality	Syntactic Complexity
Experimental Monolingual	SES-1	32	53.3	130.0
Control Monolingual	SES-1	32	25.4	52.6
Experimental Monolingual	SES-2	50	42.0	83.2
Control Monolingual	SES-2	50	15.7	36.3
Experimental Bilingual	SES-3	30	176.0	181.8
Control Bilingual	SES-3	30	29.5	39.6

The difference in means between the experimental and control groups for both monolinguals and bilinguals is significant at the 0.001 level when analysis of covariance is performed with reading grade equivalent used as covariant. Mean scores indicate that for each set the experimental treatment groups outperformed the control groups. Children in the bilingual experimental group performed significantly better than either group of monolinguals, those at SES-1 and SES-2.

Discussion

In Piaget's theory, discrepant events, such as those presented in science problems, assume a critical function in establishing the type of internal conflict necessary for intellectual development. In the Piagetian sense, one may view instruction in the generation of hypotheses as an effort to facilitate the learner's movement to a higher cognitive level of inquiry (Feldman, 1980). Furthermore,

Piaget's theory attributes an increasingly important role to language in implementing abstract thought in the stages of concrete operational thought and formal operations, stages characteristically represented by the sixth-grade 11-year-olds in this study. The role of internal conceptual conflict in cognitive development, as Piaget (1970) explains, is crucial to the position underlying this study that conceptual conflict, which triggers the processes of assimilation and accomodation needed for cognitive development, is stronger for the bilingual child than for the monolingual. In other words, that external event which sets up an internal disequilibrium is very central to cognitive reorganization and development. Science problem-solving situations, where the emphasis is upon both the quantity and quality of output, can produce fluency, flexibility, and orginality as well as quality and relevance. This view of divergent thinking provides an operational definition of certain aspects of creativity viewed as a process (Feldman, 1980).

In Piagetian terms, the disequilibration arising from two linguistic inputs may stimulate the developing bilinguals to work actively to reestablish equilibrium through the processes of assimilation and accomodation. In the hypothesiaing processes of language development, the increase in ability to observe details required by the dual language input and consequent increase in uncertainty in responding enhances the conflict between possible hypotheses regarding the linguistic rules. That state of conflict is relieved by generating additional and more acceptable hypotheses until, as an end result, the two linguistic perspectives of the bilingual are encoded. This experience, albeit subconscious, in language hypothesis generation may have a similar effect upon the capacity to generate scientific hypotheses.

Implications

These results have implications for language education as well as science education, for linguists as well as physicists, and for teachers of English as a second language as well as the science teachers who instruct bilingual students.

Findings suggest, among other things, that students educated in more than one language will be better problem-solvers than their monolingual peers.

As the research reported here supports, educational achievement and cognitive development are a function of the type of linguistic competence that the child brings to the educational program. For the bilingual child, this argues for instruction in the first language even after the primary grades in order to develop a cognitively and academically beneficial form of additive bilingualism (Cummins, 1980). This may be a significant factor in the superior performance of additive bilinguals whose first language has been more fully developed through well-implemented bilingual programs. Positive interactions between aspects of cognitive functioning, such as hypothesis formation, and bilingualism indicate that the nonuniversal achievement accomplished by bilingual children is an enrichment, often first provided in the home and community setting, that can be facilitated in specific types of educational programs in the school setting.

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